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TRACE FOSSILS FROM SILURIAN AND DEVONIAN TURBIDITES OF THE CHAUVAY AREA, SOUTHERN TIEN SHAN, KYRGYZSTAN

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Abstract: The siliciclastic turbidite successions (Pul'gon and Dzhidala Formations) that crop out in the eastern part of the Chauvay River valley, are marked on geological maps as a belt of terrigenous deposits of Silurian–Devonian age. They resemble deposits of overbank areas and depositional lobes of deep sea fans, and display common trace fossils particularly on lower surfaces of sandstone beds. Sixteen ichnotaxa representing four morphological groups have been distinguished. The trace fossil assemblages suggest their affiliation to the *Nereites* ichnofacies. Various branched, preturbidite forms predominate in both examined units, although the assemblages of individual units differ slightly in composition. In the Pulg'on Formation, small, densely distributed burrows commonly occur on lower surfaces of sandstone beds. Shallow burrowing depth together with relatively low diversity trace fossil assemblages indicate lowered oxygenation of the sea floor.

Key words: Tien Shan; Kyrgyzstan; Silurian–Devonian; turbidites; trace fossils.

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INTRODUCTION

The Central Asian part of the Variscides, including the Tien Shan Mountains, has been explored geologically for many years. Research has focused mainly on stratigraphy and structural geology (see Pickering *et al.*, 2008). The results have been published in many papers including a comprehensive atlas of the geological and palaeoenvironmental evolution of central Eurasia by Fedorenko and Militenko (2002). Data on trace fossils, at least from southern Tien Shan are, however, scanty in the easily accessible literature.

In the year 2005, one of us (MW) got a chance to explore the valley of the Chauvay River in southern Tien Shan (the Alai Mountains, southwestern Kyrgyzstan; Figs 1, 2). A significant part of the route extended across the outcrops of a siliciclastic turbidite succession marked in the geological map of the Republic of Kyrgyzstan, 1:500 000, as Silurian–Devonian clastics (cf. Burtman, 1976; Buharin *et al.*, 1985). According to the paper by Pickering *et al.* (2008), a major part of the succession represents the Silurian Pul'gon Formation. The rest belongs to the Early-Late Devonian Dzhidala Formation. Trace fossils are frequently encountered on bedding planes of thin and medium thick turbidite sandstones and mudstones of the succession. Literature studies suggest that trace fossils have not yet been closely described from these deposits. Pickering *et al.* (2008) mentioned only that bioturbation structures consisting mainly of various meandering horizontal burrows characteristic of the Nereites–Zoophycos ichnofacies are common at certain horizons of the Pul'gon Formation.

This paper aims to illustrate trace fossils recorded in the section in question, and to interpret their taxonomic affiliation and depositional environment. Particular attention has been paid to the interpretation of the chief factors responsible for the trace-fossil assemblage.

GEOLOGICAL SETTING

The Tien Shan mountain system consists of a collage of continental blocks, island arcs and accretionary prisms of various ages, which evolved into a major collisional orogene at the end of the Palaeozoic (Burtman, 1975; Allen *et al.*, 1992). The whole region was reactivated and uplifted in the Cenozoic in response to the India–Asia collision (e.g., Molnar & Tapponnier, 1975; Tapponnier & Molnar, 1979; Windley *et al.*, 1990; Sobel & Dumitru, 1997; Chen *et al.*, 1999; Poupinet *et al.*, 2002).

The southern Tien Shan, which includes the section examined in this project, is constructed of deformed Palaeo-

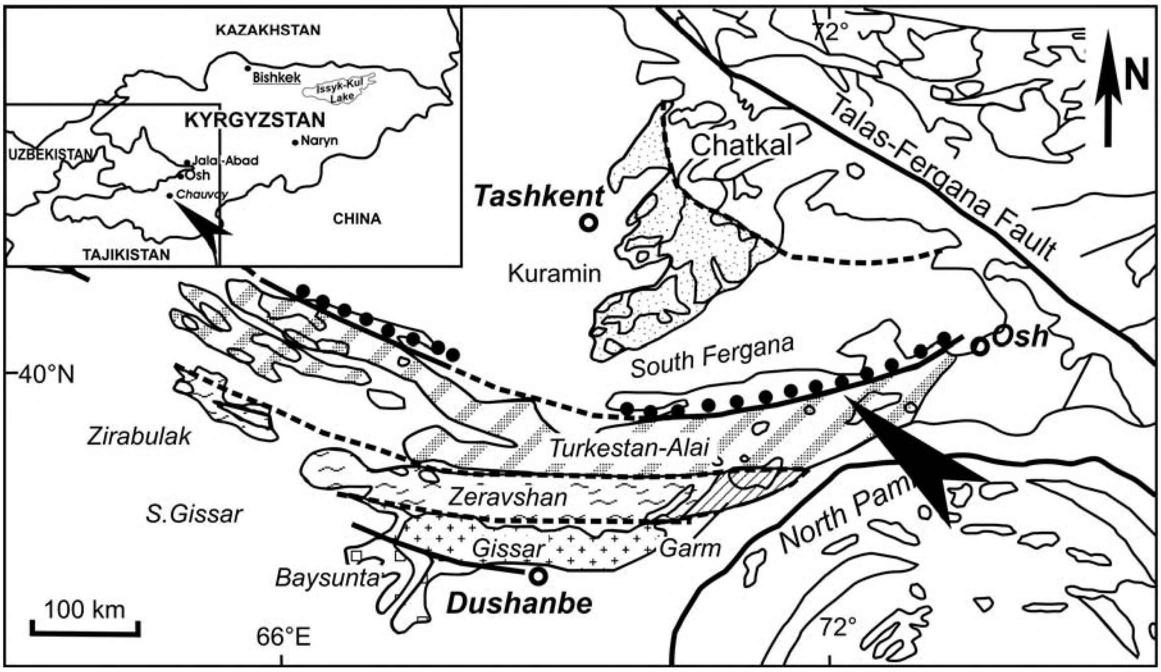

Fig. 1. Geographical and geological location of the area under study in the Tien Shan Mountains. Main structural units are shown. Modified after Brookfield (2000)

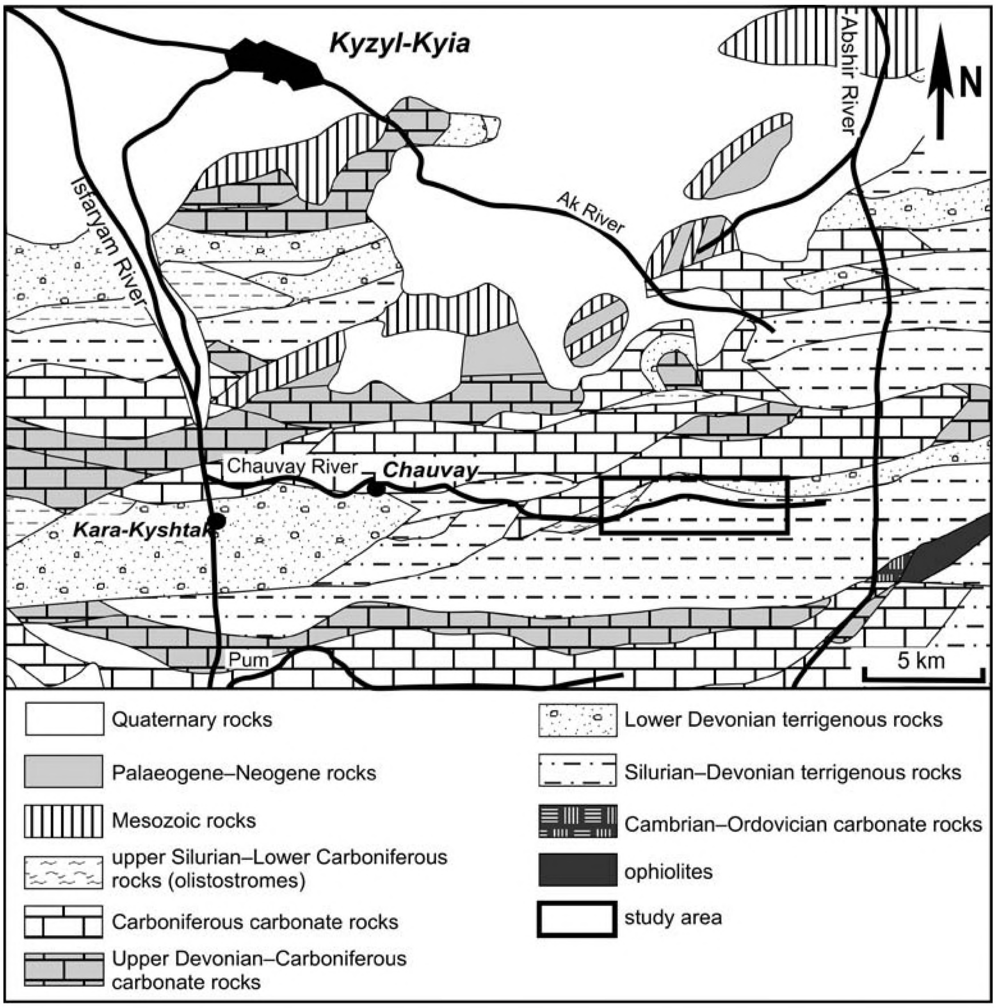

Fig. 2. Geographical and geological location map of the area under study in the close region, acc. to geological map by Bakirov (1988) and Igemberdijev (2001), modified

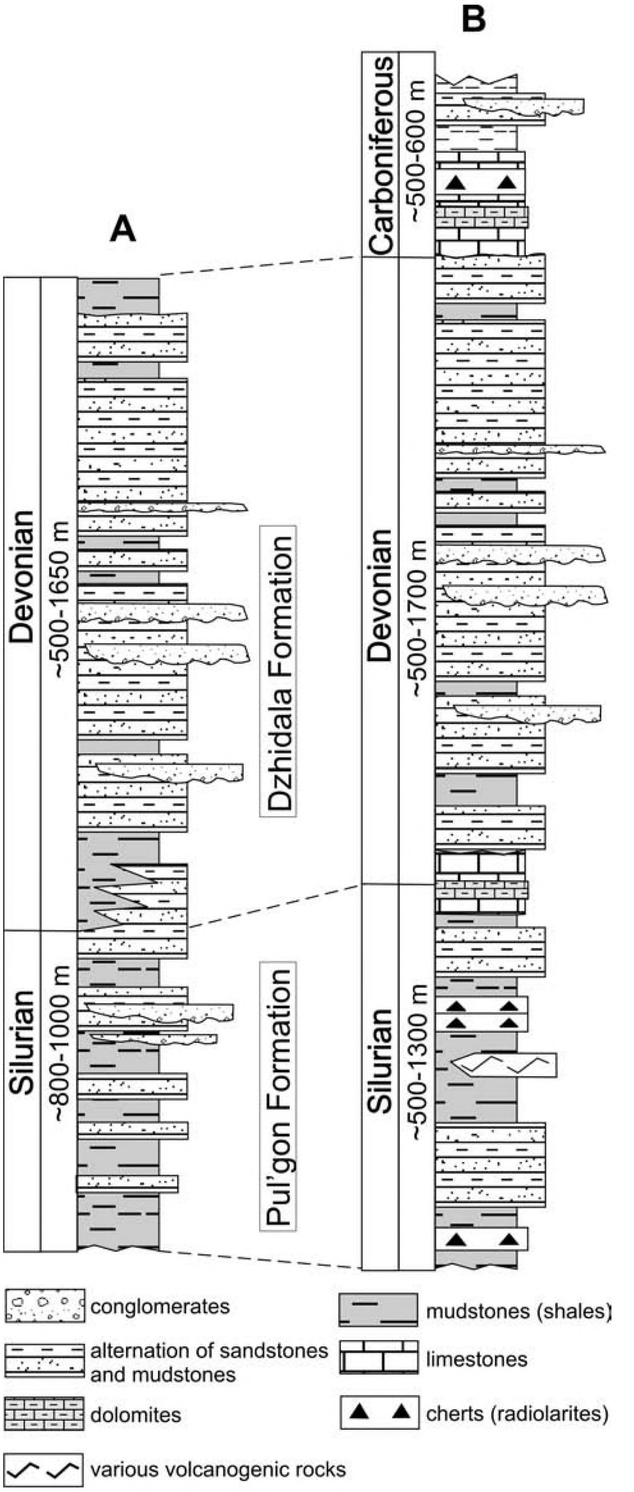

Fig. 3. Stratigraphic section of the study area: (**A**) according Pickering *et al.*, (2008); (**B**) according Buharin *et al.* (1985) and Burtman (1976), modified

zoic sedimentary rocks intruded by various plutonites (e.g., Burtman, 1975; Rogozhin, 1993; Brookfield, 2000). Several structural-facies units showing distinct tectonic features and lithostratigraphy are differentiated here (see Fig. 1; e.g., Burtman, 1975; Rogozhin, 1993; Brookfield, 2000). The section under consideration is located in the eastern segment of the Turkestan-Alai fold-and-thrust belt (cf. Pickering *et al.*, 2008) and embraces part of the Chauvayskaya unit (see Burtman, 1976; Buharin *et al.*, 1985).

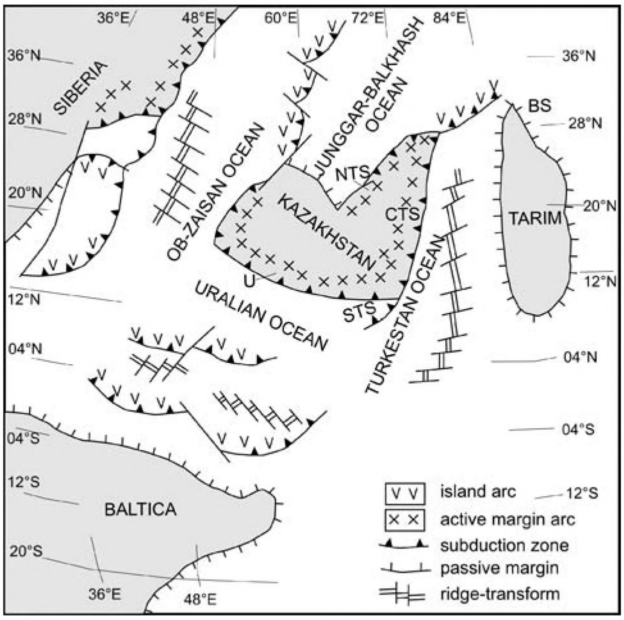

Fig. 4. Palinspastic map of the Central Asian Orogenic Belt for Early Devonian time (390 Ma). U – Ural, STS – South Tien Shan, CTS – Central Tien Shan, NTS – Northern Tien Shan. Simplified from Windley *et al.* (2007)

According to Buharin *et al.* (1985) and Burtman (1976), the rock succession of the Chauvayskaya unit in the area hosting the investigated section starts with 500–1200 m thick Silurian terrigenous clastics interbedded with volcaniclastics. These rocks pass upward into the late Silurian (Ludlovian)–Early Devonian carbonates 150–200 m thick. The carbonates are unconformably overlain by a 800–?1600 m thick succession of predominantly terrigenous siliciclastic rocks of the Early–Middle Devonian age which are overlain by Early Carboniferous carbonates and Late Carboniferous (Moscovian) siliciclastic flysch (~350–580 m thick; Fig. 3). According to Pickering *et al.* (2008), the Silurian and Devonian clastics are locally separated by mudstones, carbonates and cherts of the Kursala and Tamasha Formations, which represent specific palaeogeographic provenance. In other areas, the Silurian clastics (Pul'gon Formation) pass immediately, yet diachronously, into the Devonian clastics of the Dzhidala Formation (Fig. 3).

Different names for these units in the area in question are used in the map of a report of Persesus Mining Limited accessible on web page (Perseus report Tolubay, 2008, unpublished) and in the explanation of the geological map of Kyrgyzstan 1:500 000 (Igemberdiev, 2000), where Pickering *et al.*'s (2008) Pul'gon Formation corresponds to the Silurian Maidanskaya Suite and the Dzhidala Formation to the Devonian Karadiglinskaja Suite. The Kursala and Tamasha Formations seem to correspond in facies to the Landower Suite.

The whole sedimentary succession of the Turkestan-Alai fold-and-thrust belt was deposited in the Turkestan Ocean developed between the Kazakhstania and the Tarim continents (Fig. 4). The succession underwent severe defor-

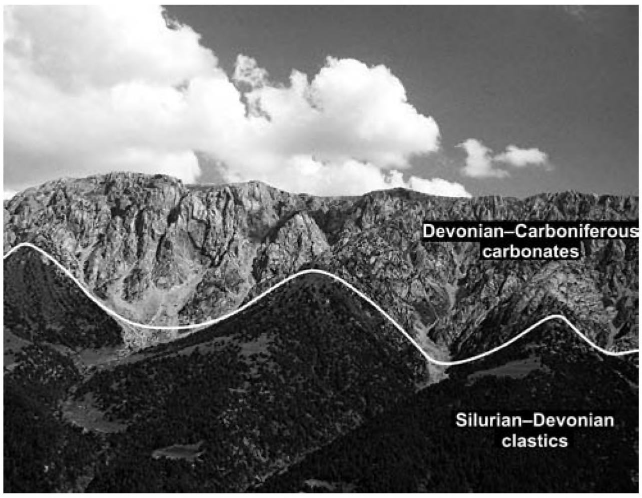

Fig. 5. View of the Chauvay River valley in the study area. The naked ridges are built of Early Carboniferous platform carbonates whereas the lower, wooded and cultivated parts of valley are composed mostly of siliciclastic rocks of Silurian and Early-Middle Devonian age

mation during the late Palaeozoic collision of these continents (Kurenkov & Aristov, 1996; Bakirov & Kakitaev, 2000; Bykadorov *et al.*, 2003; Pickering *et al.*, 2008).

The rocks examined in this project crop out at a distance of a few kilometres in the valley of the Chauvay and Kum-Bel Rivers, about 14 km east of the Chauvay River mouth (~Lat: 40°07'13"N; Lon: 72°14'04"E; 31 km south of the town Kyzyl-Kyia). The valley is bounded by the Gauzan Mountains to the north and the Ot-Salgy and Roon Tooz mountain ridges to the south. According to the geological map of the Republic of Kyrgyzstan, 1:500 000 (Igemberdiev, 2000), Silurian–Devonian clastics corresponding to the Pul'gon and Dzhidala Formations mentioned by Pickering *et al.* (2008), occur here in the lower part of the Chauvay Valley, whereas the ridges bounding the valley on both sides are built by Carboniferous carbonates (Fig. 5). According to Pickering *et al.* (2008), the Pulgon Formation was deposited in sea-floor depressions and the basin axis whereas the Dzhidala Formation was deposited on a deep-sea slope located on the margins of Kazakhstania. In part, the formations represent the fills of submarine channels, canyons or gullies.

MATERIAL AND METHODS

The investigations were performed in all pronounced outcrops of the succession in question and its material enclosed in scree and regolith. Main mesoscopic features of rocks, that is rock type, bed thickness, texture, major constituents in coarse-grained rocks, colour and structures, including the bioturbation structures, were recorded with accuracy dependent on outcrop quality and facies type.

Bioturbation structures were examined mainly on bedding planes of fragments of sandstone beds enclosed in scree and regolith. Variability of the trace fossils and distribution of particular ichnotaxa with respect to facies of the host rocks (rock type and colour, bed thickness) were recorded. Descriptions and taxonomy of trace fossils are based mainly on features recorded in photographs.

Fig. 6. Detail of lower fan turbidites. Interbedded thin-bedded and medium-bedded fine-grained sandstones and dark grey mudstones. Trace fossils are recorded mainly on sole surfaces of sandstone beds of this facies. Camera case as a scale (~10 cm)

MAIN FEATURES OF THE EXAMINED SUCCESSION

The examined succession is exposed mostly in isolated, several metres long and high outcrops scattered chiefly along the river banks. Rich information on rock features is recorded in rock fragments enclosed in talluses and regolith. Faults and folds recorded in outcrops indicate significant deformation of the whole succession. Its total thickness, including the intercalating deposits supposed to represent the Kursala and Tamasha Formations is ca. 1000 m.

The succession consists mainly of interbedded, sheet-like beds of sandstones and mudstones (shales) (Fig. 6). Several lenses of pebble conglomerates and very coarse-grained sandstones were noted in the Pul'gon Formation that crops out in the lower part of the explored valley (the upper part of the formation?). The sheet-like sandstone and mudstone beds form sandstone-mudstone couplets in the sense of their origin. They represent different "bed scale" facies of the turbidite facies association. The rocks of both lithostratigraphic units differ in colour of both the sandstones and mudstones. In the lower unit (Pul'gon Formation), the sandstones and mudstones are generally buff-coloured, whereas the upper unit (Dzhidala Formation) consists of grey sandstones and black mudstones. The grey sandstones are calcareous, whereas the mudstones are non-calcareous. In both units, the rocks are abundantly cut by calcite veins.

The sandstones of both lithostratigraphic units are fine to coarse-grained. They occur in 5 to 50 cm thick beds showing sharp, erosional bases and gradational tops. The beds show faint normal grading and Tab, Tbc divisions of the Bouma sequence, that is the non-laminated, massive division, and the parallel and ripple-cross laminated divisions respectively, whereas structures of Tde divisions (parallel laminated to non-laminated shales) occur in mudstones. The sandstone/mudstone ratio in the sheet-like bed-couplets is similar.

Lower surfaces of sandstone beds in both units are covered with different mechanoglyphs (tool marks) and bioglyphs (bioturbation structures; Fig. 7A). The latter are nearly exclusively predepositional. Endichnial and epichnial bioturbation structures are encountered rarely. The endichnial structures are recorded in thin sandstones and black mudstones (Fig. 7B, C), whereas the epichnial forms are recorded on upper surfaces of mudstones and thin sandstone beds. The amount of bioturbation structures seems to be higher in the buff-coloured sandstones (Pulgon Formation) than in the grey sandstones (Dzhidala Formation). Moreover, small burrows are much more frequent in the first-mentioned unit. Features of the sandstone-mudstone sheet-like couplets imply deposition in depositional lobes of deep sea fans and in overbank areas.

The lenses of conglomerates and very coarse-grained sandstones are a few metres thick. The sandstones in the lenses are massive. The deposits show thining- and fining-upward trends, whereas the bases of the lenses are clearly erosional. These features imply that the deposits represent fills of gullies or small channels.

TRACE FOSSILS

The trace fossils recorded in both explored units show significant variability in morphology, pattern and size. Seventeen forms have been distinguished in the assemblages in total. Each of them, except one, appears to represent different ichnotaxon. Different branched trace fossils are the most common, particularly in the Pul'gon Formation. The majority of other forms was recorded as single specimens only.

The trace fossils were subdivided into four morphological groups following the classification scheme of Książkiewicz (1970, 1977). Individual groups include one to several taxa displaying specific morphology, pattern and size, and representing one to several ichnogenera and ichnospecies. Each form showing specific morphology, pattern and size was described separately. Majority of trace fossil forms was identified tentatively because of poor quality of the collected specimens.

Simple structures

1. Straight to slightly curved, smooth-walled ridges, 2 mm wide, recorded usually in fragments less than 20 mm long, unbranched (Fig. 7A: a). They occur sparsely dispersed at lower surfaces of sandstone beds. Their arrangement suggests that they may represent fragments of burrows of different ichnotaxa, particularly of the ichnogenera *Chondrites* and *Megagrapton*. Trace fossils of this type were recorded in both examined units.
2. Hypichnial ridges, 4 mm wide, gently curved, smooth-walled, unbranched (Fig. 7A: b). According to shape and size, these burrows correspond to *Planolites beverleyensis* (Billings 1862), (cf. Pemberton & Frey, 1982, pl. 5) and are here considered as representing this ichnotaxon. They were observed in both examined units.
3. Hypichnial ridges, 6–7 mm wide, straight, rarely slightly curved, thinly lined, smooth-walled, unbranched (Fig. 7A: c). According to the named features, these burrows represent *Palaeophycus tubularis* Hall 1847, (see Pemberton & Frey, 1982, pl. 1, fig. 8). Burrows of this type were recorded in both examined units.

Branched structures

1. Hypichnial burrows 0.8–1.2 mm wide, usually as much as 15 mm long, rather smooth-walled, horizontally and vertically curved, showing branching at angles 30–50° (Fig. 7D: a). In some cases, branching appears to be dichotomous. Individual ramified branches are chaotically oriented. Taxonomic affiliation of these trace fossils remains unclear. They may represent a new ichnotaxon; however, precise classification is difficult because of poor preservation in the recorded specimens. They occur together with thread-like, curved, winding unbranched ridges of *Helminthopsis* isp.

2. 'Vermicular', horizontally and vertically curved and branched ridges and knobs, 2.5 mm wide, randomly distributed on the lower surface of sandstone beds (Fig. 7E) in the Pul'gon Formation. True branching seems to be rare. According to the style of burrow course and branching it resembles *Planolites montanus* Richter 1937. However, because of scarce data it is detemined here as cf. *Planolites montanus* Richter 1937.

3. Systems of hypichnial ridges 2 mm thick, showing multiple dichotomous branching (Fig. 7F). The ridges appear to be radially arranged, however, radiation in one direction only is recorded in the described specimen. According to the style of branching, ridges arrangement and burrow size, the trace fossil seems to be most closely related to *Glockerichnus dichotoma* (Seilacher 1977), (see Seilacher, 1977, *Glockeria dichotoma* n. isp.). It is determined here as ?*Glo- ckerichnus dichotoma* (Seilacher 1977).

4. Hypichnial ridges of changing thickness 4–7 mm, sligh- tly curved, irregularly-walled, showing Y-shaped branching at angles 30–70° (Fig. 7G: a, H). Some ridges display irregularities on their sides, appearing to represent failed bran- ches. A trace fossil showing similar sizes, and branching pattern was described by Osgood (1970, pl. 63,

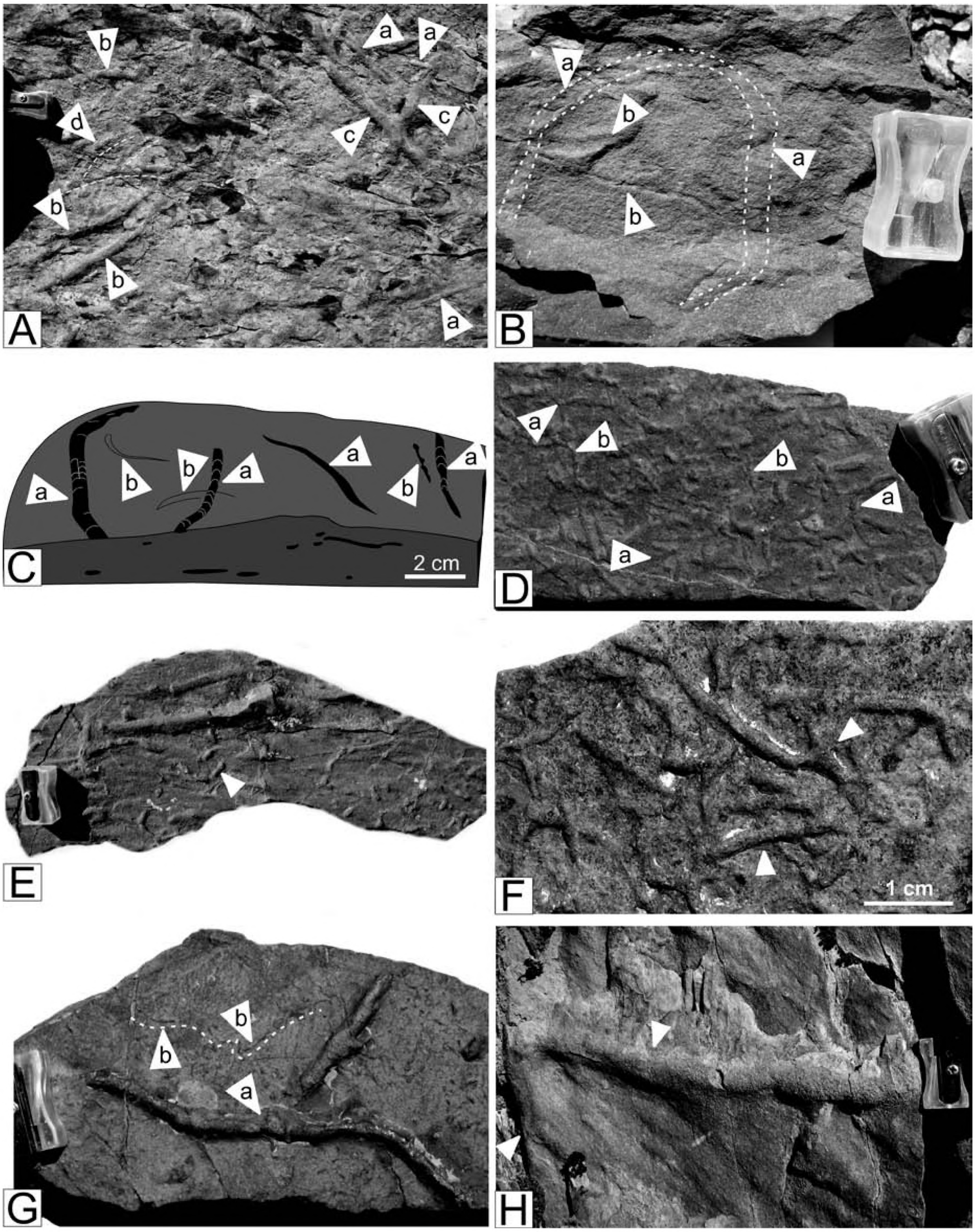

Fig. 7. **A** – Lower surface of sandstone bed showing several linear burrows of three size classes and different taxonomic affiliation. The thinnest burrows (a) represent fragments that are ichnotaxonomically undetermined. The larger forms represent *Planolites beverleyensis* (b) and *Palaeophycus tubularis* (c), some burrows appear to show multiple branching (d), Dzhidala Formation; sharpener 2.5 cm long; **B** – endichnial ?*Nereites missouriensis* (a) faintly marked with fine-grained fill (structure of fill not visible in this photo) and taxonomically indetermined burrows (b), dark-grey mudstone, Dzhidala Formation; sharpener 2.5 cm long; **C** – ?*Nereites missouriensis* (a; vague halo not marked) and taxonomically indetermined burrows (b), seen in horizontal (above) and vertical section, redrawn from a specimen of dark-grey mudstone, Dzhidala Formation; **D** – predepositional, irregularly branched, curved burrows (a) and faint *Helminthopsis* isp. (b); convex hyporelief, sandstone bed from Pul'gon Formation; **E** – Vermicular, curved and branched ridges cf. *Planolites montanus*; convex hyporelief, sandstone bed, Pul'gon Formation; **F** – cf. *Glockerichnus dichotoma* (marked with arrows); convex hyporelief, sandstone bed, Pul'gon Formation; **G** – *Thallassinoides suevicus* (a) superimposed upon poorly recorded, thin, curved, undetermined branched burrows (b), lower surface of sandstone bed, Pul'gon Formation; sharpener 2.5 cm long; **H** – *Thallassinoides suevicus* (marked with arrows) on the lower surface of sandstone bed; sharpener 2.5 cm long

fig. 5) as *Chondrites gracilis* var. *crassa* Hall. Książkiewcz (1977) described similar burrows as undetermined ichnospecies of *Buthotrephis*. According to Uchman (1998), trace fossils showing these features represent *Thallassinoides suevicus* (Rieth 1932). This interpretation is also followed here. Trace fossils of this category were recorded in both examined units.

5. Hypichnial, slightly winding to nearly straight, convex semireliefs 3–4.5 mm wide, showing a smooth to slightly irregular surface, and dichotomously, Y-shaped branching at the end (Fig. 8A–E). The angle of branching is 35–40°. The part of the burrow located before branching (the stem) is shorter than the arms. The latter are as much as 50 mm long. Taxonomic affiliation of these trace fossils is not clear. Their shape is similar to individual bifurcated arms of *Glockerichnus alata* (Seilacher 1977). However, in contrast to this ichnotaxon, they appear to not occur radially arranged. Burrows similar in size and form but recorded at the upper surface of sandstone beds were described by Bradshaw (1981, fig. 37) from the Devonian of Antarctica, simply as epichnial ridges. The forms in question were recorded in both units.

6. A system of hypichnial, curved ribs, 3.5–4 mm wide and 20–30 mm long, appearing to stem from a 10 mm wide trunk (Fig. 8F). The ribs are oriented at an angle of 30–60° relative to the trunk. The structure was recorded in one poorly preserved specimen from the Pul'gon Formation. Its taxonomic affiliation is unclear. The size and shape of ribs as well as their arrangment are similar as in *Fascisichnium extentum* Książkiewicz 1968. However, only one side of the system (trunk and ribs on one side) is recorded in the described specimen.

Meandering and winding structures

1. Hypichnial, irregularly meandering, thread-sized trace fossil, 1 mm wide (Fig. 9A: a). It shows wide, shallow meanders and deep, narrow, obtuse meanders. Because of the named features it is determined here as *Helminthopsis tenuis* Książkiewicz 1968 (cf. Uchman, 1998). It was recorded in the Dzhidala Formation only.

2. Hypichnial, loosely winding ridges, 0.5 mm wide, non branched (Fig. 7D: b). Similar trace fossils were shown by Wetzel and Bromley (1996, text-fig. 5) as of uncertain taxonomy, supposed mycelia or juvenile *Helminthopsis*. The style of winding of the forms described here seems to be such as in the ichnogenus *Helminthopsis*, therefore they are classified here as *Helminthopsis* isp. They were recorded in the Dzhidala Formation.

3. Endichnial, strongly flattened strings, 4 mm wide, gently winding, unbranched, roughly parallel to bedding, recorded in mudstones (7B: a, 7C). They are faintly marked with the fill which is finer-grained and darker than the surrounding sediment. The burrow fill appears to be flanked with a halo marked by slightly lighter colour than that of the fill. The fill seems to be homogeneous in some burrow fragments. In some other burrow fragments, it appears to show a faint meniscate structure with irregularly spaced parabolic menisci, or a flattened pustular structure with paired pustules (Fig. 7C). The mentioned features suggest affiliation of the trace fossil with *Nereites missouriensis* (Weller 1899). Restriction of the pustular fill to some burrow fragments may result from its preservation style. The trace fossil is classified here as ?*Nereites missouriensis* (Weller 1899). Neither epichnial nor hypichnial variants of the trace fossil have been found. The trace fossil was recorded in the Dzhidala Formation only.

4. Hypichnial meandering ridge, 5–7 mm wide, recorded in one specimen showing two turns only (Fig. 9A: b). The turns are ca. 30 mm high. One turn is sharp the other is rounded. A protuberance occurs on the apex of the sharp turn. The style of bending and the protuberance at one turn make this trace fossil similar to some specimens of *Protopaleodictyon incompositum* Książkiewicz 1970 (see Książkiewicz, 1977, text-fig. 40: a). It is much thicker than the specimens described by Książkiewicz (1977) from the Cretaceous–Palaeogene flysch of the Polish Carpathians but is of similar tickness as the forms mentioned by Crimes and Crossley (1991) from the Silurian flysch of Wales. Considering the above mentioned features, and particularly its incomplete form, the specimen is determined with as ?*Protopaleodictyon incompositum* Książkiewicz 1970. It was found in the Dzhidala Formation

5. Hypichnial, winding to meandering ridge, 4 mm wide (Fig. 9B). Meanders irregular and horseshoe-like, 10–30 mm high. The described specimen corresponds in size and general shape to *Helminthopsis abeli* Książkiewicz 1977. However, it shows distinct protuberance at one turn and an appendage seems to branch from another turn. These features suggest affiliation with ichnogenus *Protopaleodictyon* Książkiewicz 1958. Because of single occurence and poor quality of the specimen it is determined as ?*Protopaleodictyon* isp. It was recorded in the Dzhidala Formation.

6. Hypichnial, unbranched, unsculptured, unornamented, looping ridges, approximately 2 mm wide, several centimetres long, developed roughly parallel to bedding (Fig. 9C). They occur as overlapping loops of a diameter as much as 4 mm, showing variable horizontal arrangement. According to size and looping style these burrows are included here to *Gordia* isp. as described by Fillion and Pickerill (1990, pl. 7, fig. 15). These burrows were recorded in the Dzhidala Formation only.

7. A system of closely spaced, nearly parallel, slightly curved pairs of flattened ridges, each 0.8 mm wide, separated by a 0.4 mm wide furrow (Fig. 9D), recorded on the lower surface of sandstone beds of the Pul'gon Formation. The trace fossil resembles in general pattern and size *Agrichnium bruhmi* Pfeifer (1969). However, according to Pfeifer (1969), the diagnostic features of this trace fossil are parallel furrows and not ridges as in the here described specimen. Actually, Pfeifer (1969) has not mentioned a toponomic origin of his specimens. The burrow seems to form tight, high amplitude horizontal meanders similar in style to that of *Taphrhelminthopsis* preservation of *Scolicia* (see Seilacher, 2007). Its producer must have followed a thigmotactic burrowing strategy (see Seilacher, 2007). It is determined here as aff. *Agrichnium* aff. *bruhmi* Pfeifer.

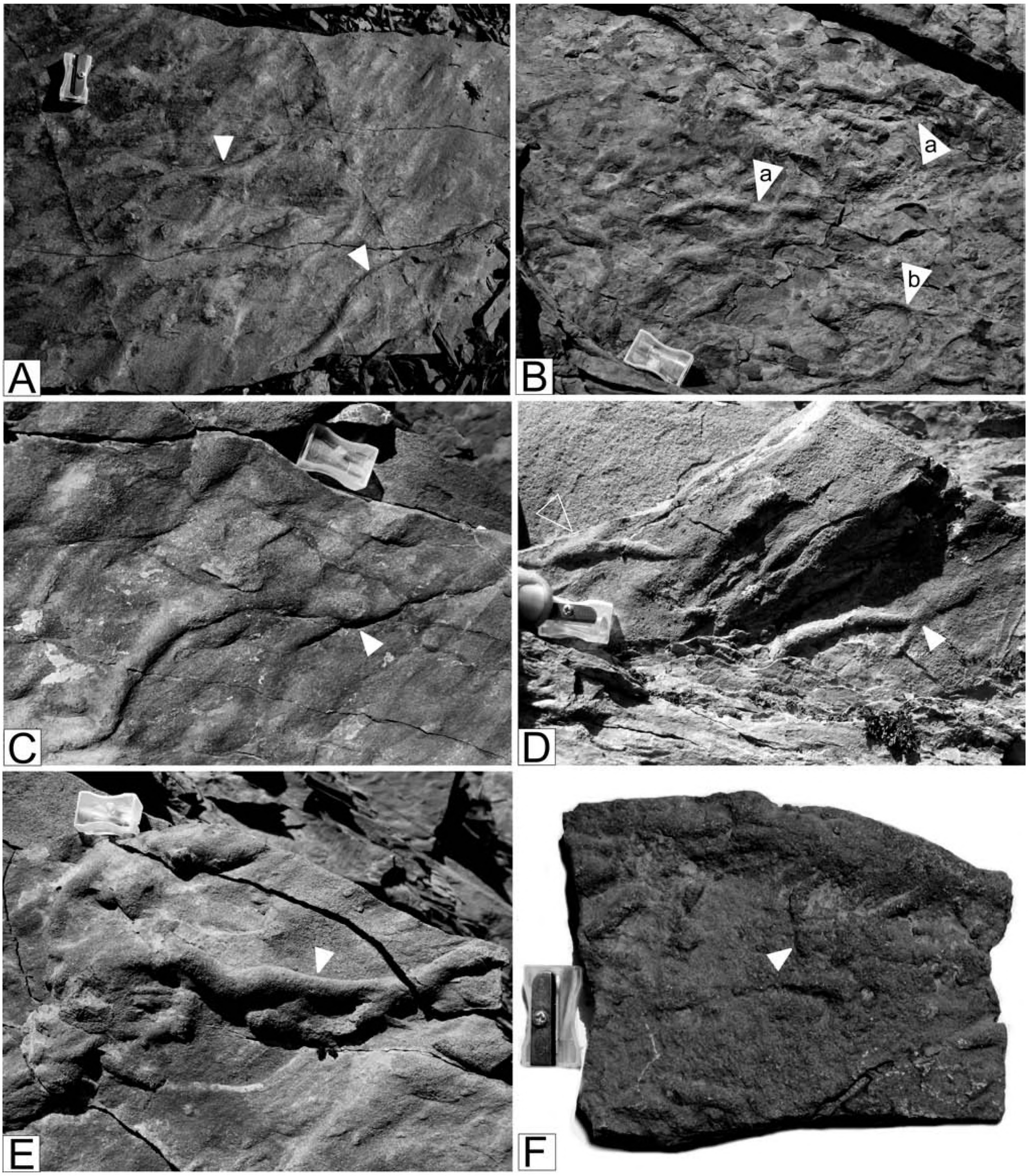

Fig. 8. **A** – Poorly preserved, partly washed out, dichotomously branched burrow (marked with arrow); convex hyporelief, sandstone bed; **B** – Dichotomously branched, straight to slightly curved burrow (a) and thin winding burrow ?*Helminthopsis* isp. (b); convex hyporeliefs, sandstone bed; **C** – Dichotomously branched, slightly curved, partly washed out burrow (marked with arrow); convex hyporelief, sandstone bed; **D** – Dichotomously branched burrows (marked with arrow); convex hyporelief, sandstone bed; **E** – Dichotomously branched, slightly curved, partly washed out burrow (marked with arrow), convex hyporeliefs, sandstone bed; Dzhidala Formation; **F** – Poorly preserved ?ramified trace fossil of uncertain taxonomy (marked with arrows); convex hyporelief, sandstone bed, Pul'gon Formation. Sharpener 2.5 cm long as a scale. Specimens A–E from Dzhidala Formation

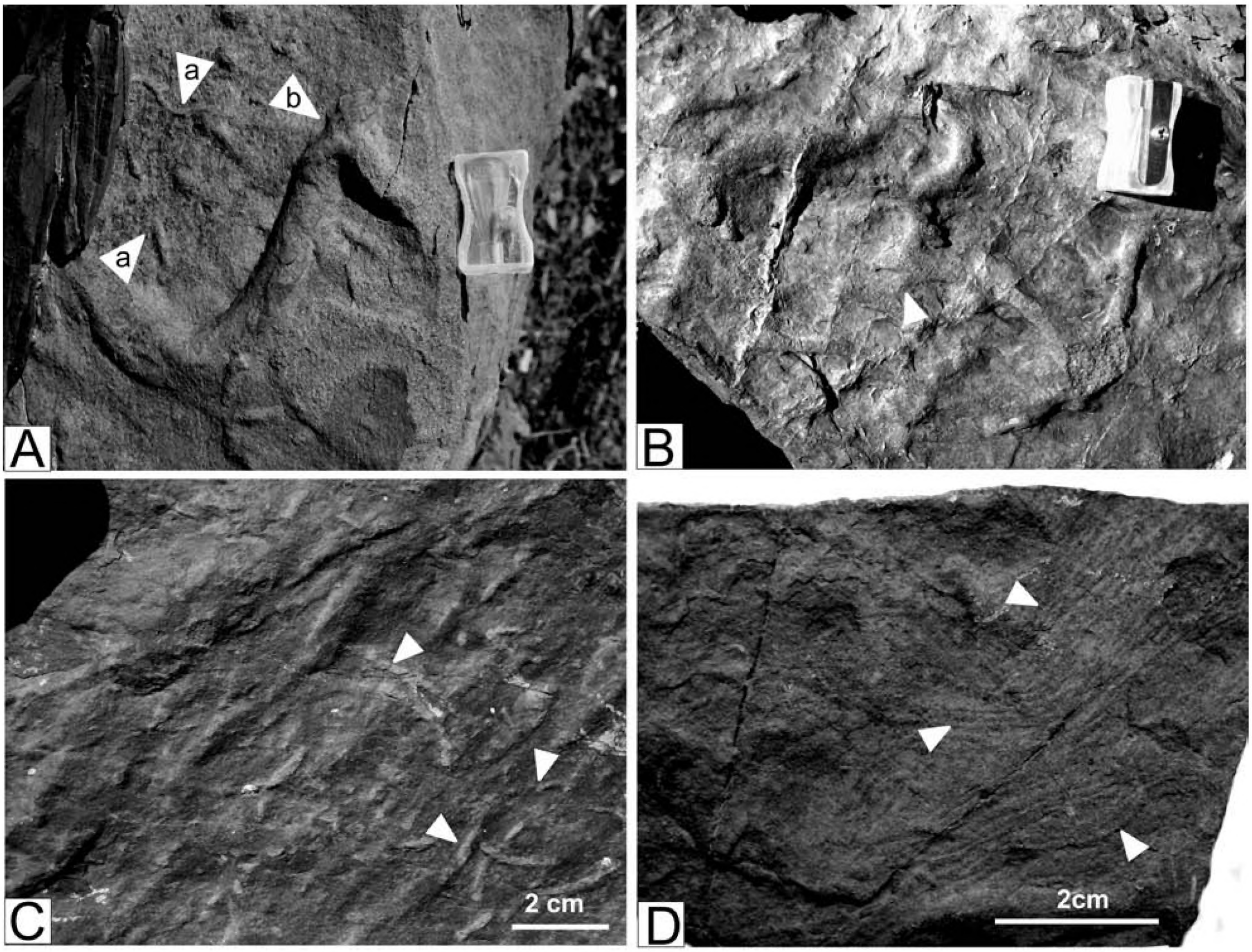

Fig. 9. **A** – *Helminthopsis tenuis* (a) and ?*Protopaleodictyon incompositum* (b; arrow indicates protuberance at apex of sharp turn), convex hyporelief, sandstone bed, Dzhidala Formation; sharpener 2.5 cm long; **B** – ?*Protopaleodictyon* isp., arrow indicates protuberance at burrow bend; convex hyporelief, sandstone bed, Dzhidala Formation; sharpener 2.5 cm long; **C** – *Gordia* isp. (marked with arrows), convex hyporelief, sandstone bed, Dzhidala Formation; **D** – aff. *Agrichnium* aff. *bruhmi* (marked with arrows); hyporelief, sandstone bed, Pul'gon Formation

Network structures

1. Hypichnial, convex, string-size burrows (2 mm wide), winding, forming an irregular net with meshes several centimetres across. The strings show branching at approximately right angles (Fig. 10). The size and pattern of this burrow system evidence that it represents *Megagrapton irregulare* Książkiewicz 1968 (see Książkiewicz, 1977, pl. 25, figs 6–8). In many specimens, poorly preserved, winding thread-size burrows are recorded that seem also to show branching and appear to also resemble *Megagrapton* (Fig. 7G: b).

DISCUSSION

Features of the investigated rocks indicate their deposition mainly by turbidity currents well below storm wave base. A subordinate part of mudstones, that is, those in the top part of mudstone beds, may represent deposits of normal, pelagic and/or hemipelagic sedimentation. Common, almost flat lower surfaces of sandstone beds, suggest rather subordinate erosion of the sea floor by the turbidity currents. Predominance of predepositional trace fossils to-

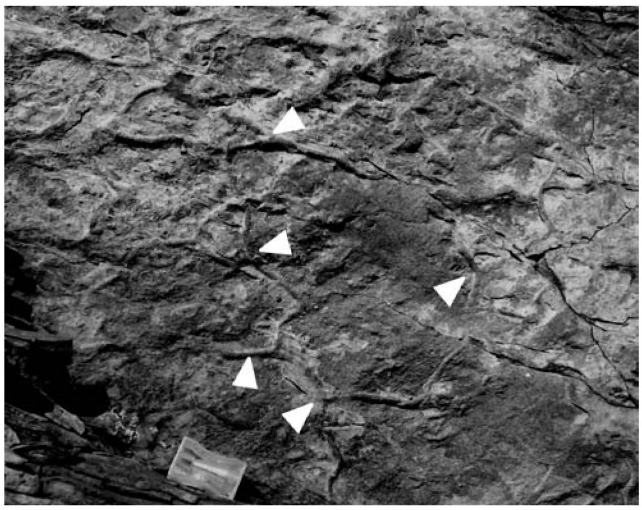

Fig. 10. Megagrapton *irregulare* (branching marked with arrows); convex hyporelief, sandstone bed, Dzhidala Formation; sharpener 2.5 cm long

gether with rare occurrence of endichnial burrows in sandstones and shales of both units imply shallow burrowing depths. Poor oxygenation of the sea floor is the chief factor responsible for the shallow burrowing depths in general (see Savrda *et al.*, 1991). Actually, the dark colour of the shales of the Dzhidala Formation, denoting increased organic matter content, together with shallow burrowing depths as well as the relatively poor trace fossil assemblage, suggest lowered oxygenation of benthic water and location of the redox boundary close to the sediment/water interface in the sedimentary area of this unit. Lowered benthic oxygenation could have occurred also during sedimentation of the Pul'gon Formation, despite the fact that the light colours of its fine-grained deposits suggest the opposite. The light colours of mudstones may result from a low supply of organic matter during sedimentation of this unit and are irrelevant to the sea-floor oxygenation. Moreover, a predominantly easily degradable organic matter that escaped burial even in poorly oxygenated areas could have been supplied there. Such a scenario is suggested by high abundance of small burrows recorded on the lower surfaces of sandstone beds. High concentration of burrows together with low variability of their forms implies that the sediment was poorly oxygenated and sufficiently rich in food.

Lithofacies of both units suggest sediment supply typical of areas distant to the main routes of sediment transportation and of times of elevated sea level. According to Pickering *et al.* (2008), the Silurian–Devonian rocks of the Alai range, which includes the area in question, represent remnants of a forearc accretionary prism and were deposited both on a slope and in a basin.

The trace fossils recorded in the investigated successions indicate production by mobile endobenthos, mainly due to feeding activity. The assemblage together with the host lithofacies suggests its affiliation with the *Nereites* ichnofacies. However, *Megagrapton irregulare* Książkiewicz is the only evident ichnotaxon indicative of this ichnofacies. Of the other taxa, ?*Nereites missouriensis* (Weller 1899), ?*Glockerichnus dichotoma* (Seilacher 1977), *Helminthopsis tenuis* Książkiewicz 1968, *H.* isp., ?*Protopaleodictyon incompositum* Książkiewicz 1970 and ?*P.* isp. strongly support the ichnofacies interpretation, though, except one, they were interpreted with uncertainty. Paucity of graphoglyptids and occurence of forms that appear to represent ichnotaxa not mentioned yet from other localities, make the assemblage hardly comparable with those known from the mid-Palaeozoic turbidites of other regions. Its individuality may result from some isolation of the sedimentary basin from the world ocean, its palaeogeographic location and benthic oxygenation regime. Isolation of the sedimentary area was higly probable in the light of interpretation of the origin of the Silurian–Devonian formations of this area in front of a prograding accretionary prism (Pickering *et al.*, 2008).

CONCLUSIONS

1. The siliciclastic turbidite successions outcropped in the eastern part of the Chauvay River valley, and marked on geological maps as of Silurian–Devonian age resemble deposits of overbank areas and depositional lobes of deep sea fans or apron systems.

2. The sandstones of the successions show various trace fossils particularly on the lower surfaces of beds. Various branched, preturbidite forms predominate in the assemblages of both examined units, although the assemblages of individual units differ slightly in composition. In the Pul'gon Formation, small, densely distributed burrows occur commonly on lower surfaces of sandstone beds. Only one endichnial form (ichnospecies) has been recorded in shales.

3. Taxonomic affiliation of the majority of trace fossils recorded in the successions remains equivocal due to their occurrence as single, poorly preserved specimens only. Nevertheless, a total of sixteen ichnotaxa have been distinguished in the assemblage. Some forms may represent new ichnotaxa.

4. The trace fossil assemblage recorded in the investigated section together with the host lithofacies suggests affiliation with the *Nereites* ichnofacies. However, the assemblage is impoverished in graphoglyptids.

5. A relatively poor trace fossil assemblage together with shallow burrowing depths in both units suggest poor oxygenation of the benthic water and rather dysoxic conditions at the bottom of the sedimentary basin. Different colours of shales seem to result from distinct amounts and type of organic matter supplied to the sea bottom. The light colour of shales in the Pul'gon Formation may result from a low supply of mainly non-refractory organic matter to the sedimentary area. In contrast, dark colour of shales of the Dzhidala Formation suggests increased supply of organic matter to its sedimentary area. Deposition of the succession in a restricted sedimentary basin seems to be highly probable.

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